# CLEAR AIR TURBULENCE

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# Revision Record

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# INTRODUCTION

Turbulence is one of the most unexpected aviation hazards to fly through and also is one of the most difficult hazards to forecast. Serve and extreme turbulence has been known to cause extensive structural damage, with lesser cases resulting in compressor stalls, flameouts, and injury to crew members and passengers. From minor bumps to severe mountain wave turbulence, turbulence comes in many forms and is usually worst during the winter months. For this Specific Briefing we are concentrating on Clear Air Turbulence.

# CATEGORIES OF TURBULENCE INTENSITY

Turbulence is categorised as light, moderate, severe and extreme. Each category is defined in terms, which are perceived by the pilot in term of effects on the aircraft and its occupants. Weather forecasters use the same four categories when forecasting on their significant weather charts.

**Levels of Turbulence**

- **Light Turbulence** that momentarily causes slight erratic changes in altitude and/or attitude (pitch, roll, yaw). Report as “Light Turbulence”.

  OR

  Turbulence that causes slight, rapid and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude. Report as “Light Chop”. Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Little or no difficulty is encountered in walking.

- **Moderate Turbulence** that is similar to “Light Turbulence” but of greater intensity. Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times. It usually causes variations in indicated airspeed. Report as “Moderate Turbulence”.

  OR

  Turbulence that is similar to “Light Chop” but of greater intensity. It causes rapid bumps or jolts without appreciable changes in aircraft altitude or attitude. Report as “Moderate Chop”. Occupants feel definite strains against seat belts or shoulder straps. Unsecured objects are dislodged. Walking is difficult.

- **Severe Turbulence** that causes large, abrupt changes in altitude and/or attitude and large variations in indicated airspeed. Aircraft may be momentarily out of control. Report as “Severe Turbulence”. Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Walking is impossible.

# CLEAR AIR TURBULENCE CAT

The term clear ait turbulence (CAT) is commonly used to denote the rough, washboard-like bumpiness which ranges from a few annoying bumps to serve jolts capable of causing structural damage to airframes and injury to passengers. CAT is not restricted to cloud-free air. It occurs in cirrus cloud and haze layers with no visual

warnings. Studies show that only about 75 percent of all CAT encounters are in clear air.

Clear air turbulence differs from convective and mechanical turbulence in that it is more rhythmic in nature than random. CAT is usually found above 15000ft, outside of convective clouds, in association with a marked change in wind speed or temperature, either with height (vertical wind shear) and/or in the horizontal (horizontal wind shear). Not all CAT is associated with jet streams, but is the most likely location of CAT.

# EXCERPTS FROM FAA ADVISORY CIRCULAR 00-30B

**Atmospheric Turbulence Avoidance**

This advisory provides discussion and recommendations that provide information on avoiding or minimising encounters with CAT.

- Describes various types of CAT.
- Some weather patterns associated with CAT.
- Rules of thumb for avoiding or minimising.
- Encounters with CAT.

Although based on Northern Hemisphere conditions, the information applies equally to Southern Hemisphere.

## BACKGROUND

In 1966, the National Committee for Clear Air Turbulence officially defined CAT as "all turbulence in the free atmosphere of interest in aerospace operations that is not in or adjacent to visible convective activity (this includes turbulence found in cirrus clouds not in or adjacent to visible convective activity)." Over time, less formal definitions of CAT have evolved. The Aeronautical Information Manual expands on the basic CAT definition as "turbulence encountered in air where no clouds are present." This term is commonly applied to high level turbulence associated with windshear. Thus, clear air turbulence or CAT has been defined in several ways, but the most comprehensive definition is: "turbulence encountered outside of convective clouds." This includes turbulence in cirrus clouds, within and in the vicinity of standing lenticular clouds and, in some cases, in clear air in the vicinity of thunderstorms. Generally, though, CAT definitions exclude turbulence caused by thunderstorms, low altitude temperature inversions, thermals, or local terrain features.

CAT was recognised as a problem with the advent of high altitude jet operations in the 1950s. CAT is especially troublesome because it is often encountered unexpectedly and frequently without visual clues to warn pilots of the hazard.

## DISCUSSION

One of the principal areas where CAT is found is in the vicinity of the jetstream or jetstreams. A jetstream is a river of high altitude wind with a speed of 50 knots, or greater, following the planetary atmospheric wave pattern. There are, in fact, three

jetstreams: the polar front jetstream, the subtropical jetstream, and the polar night jetstream.

- The **polar front jetstream** as its name implies, is associated with the polar front or the division between the cold polar and warm tropical air masses. The mean latitude of the jetstream core varies from 25° north latitude during the winter months to 42° north latitude during the summer months. It is the centre of the planetary wave pattern and as such meanders over a large portion of the hemisphere throughout the year, particularly during the winter months when it is most intense. Although the polar front jetstream varies in altitude, the core is most commonly found around 30,000 feet and it is generally best depicted on the 300 millibar constant pressure map.

- The **subtropical jetstream** is a very persistent circumpolar jetstream found on the northern periphery of the tropical latitudes between 20° and 30° north latitude. It normally forms three waves around the globe with crests over the eastern coasts of Asia and North America and the Near East. Like the polar front jetstream, the subtropical jetstream is most active during the winter months and often intrudes well into the southeastern United States. It is generally higher than the polar front jetstream with the core between 35,000 and 45,000 feet.

- The **polar night jetstream** is found in the stratosphere in the vicinity of the Arctic Circle during the winter months and does not have a significant affect on air travel over the United States and southern Canada.

CAT associated with a jetstream is most commonly found in the vicinity of the tropopause (a very thin layer marking the boundary between the troposphere and the stratosphere) and upper fronts. Analyses of the tropopause are issued by the National Weather Service on a scheduled basis. In the absence of other information, the tropopause will generally have a temperature of between -55 °C. and -65 °C. In some cases, it will be at the top of a cirrus cloud layer. Clouds are very seldom found above the tropopause in the dry stratosphere, except in the summertime when occasionally large thunderstorms will poke through the tropopause and spread anvil clouds in the stratosphere. CAT is most frequently found on the poleward side of the jetstream (the left side facing downwind). It is additionally common in the vicinity of a jetstream maxima (an area of stronger winds that moves along the jetstream).

There are several patterns of upper level winds that are associated with CAT. One of these is a deep, upper trough. The CAT is found most frequently at and just upwind of the base of the trough, particularly just downwind of an area of strong temperature advection. Another area of the trough in which to suspect CAT is along the centerline of a trough where there is a strong horizontal windshear between the northerly and southerly flows. CAT is also found in the back side of a trough in the vicinity of a wind maxima as the maxima passes through.

One noteworthy generator of CAT is the confluence of two jetstreams. On occasion, the polar front jetstream will dip south and pass under the subtropical jetstream. The windshear effect of the jetstream between the two jetstreams in the zone of confluence and immediately downstream is highly turbulent.

CAT is very difficult to predict accurately, due in part to the fact that CAT is spotty in both dimensions and time. Common dimensions of a turbulent area associated with a jetstream are on the order of 100 to 300 miles long, elongated in the direction of the

wind, 50 to 100 miles wide, and 5,000 feet deep. These areas may persist from 30 minutes to a day. In spite of the difficulty forecasting CAT, there are rules that have been developed to indicate those areas where CAT formation is likely.

The threshold windspeed in the jetstream for CAT is generally considered to be 110 knots. Windspeed in jetstreams can be much stronger than 110 knots and the probability of encountering CAT increases proportionally with the windspeed and the windshear it generates. It is not the windspeed itself that causes CAT; it is the windshear or difference in windspeed from one point to another that causes the wave motion or overturning in the atmosphere that is turbulence to an aircraft. Windshear occurs in all directions, but for convenience it is measured along vertical and horizontal axes, thus becoming horizontal and vertical windshear. Moderate CAT is considered likely when the vertical windshear is 5 knots per 1,000 feet, or greater, and/or the horizontal windshear is 40 knots per 150 nautical miles, or greater.

# EXCERPTS FROM APPENDIX 1 FAA AC 00-30B

## A Model For A Clear Air Turbulence Avoidance System

- Jetstreams stronger than 110 knots (at the core) have potential for generating significant turbulence near the sloping tropopause above the core, in the jetstream front below the core, and on the low pressure side of the core.

- Windshear and its accompanying CAT in jetstreams is more intense above and to the lee of mountain ranges. CAT should be anticipated whenever the flightpath traverses a strong jetstream in the vicinity of mountainous terrain.

- Both vertical and horizontal windshear are, of course, greatly intensified in mountain wave conditions. Therefore, when the flightpath traverses a mountain wave type of flow, it is desirable to fly at turbulence penetration speed and avoid flight over areas where the terrain drops abruptly, even though there may be no lenticular clouds to identify the condition.

- On charts for standard isobaric surfaces, such as 300 millibars, if 20 knot isotachs are spaced closer together than 150 nautical miles (2 ½ degrees latitude), there is sufficient horizontal shear for CAT. This area is normally on the poleward (low pressure) side of the jetstream axis.

- Turbulence is also related to vertical shear. From the tropopause height/vertical windshear chart, determine the vertical shear in knots per thousand feet. If it is greater than 5 knots per 1,000 feet, turbulence is likely.

- Curving jetstreams are more apt to have turbulent edges than straight ones, especially jetstreams which curve around a deep pressure trough.

- Wind shift areas associated with pressure troughs and ridges are frequently turbulent. The magnitude of the windshear is the important factor.

# "RULES OF THUMB" FOR TURBULENCE AVOIDANCE

The following "Rules of Thumb" apply primarily to the turbulence associated with the westerly jetstreams.

a) If jetstream turbulence is encountered with direct tailwinds or headwinds, the pilot should consider a change of flight level or course since these turbulent areas are elongated with the wind and are shallow and narrow.

b) If jetstream turbulence is encountered in a crosswind, it is not so important to change course or flight level since the rough areas are narrow across the wind.

c) If turbulence is encountered in an abrupt wind shift associated with a sharp pressure trough line, establish a course across the trough rather than parallel to it.

d) If turbulence is expected because of penetration of a sloping tropopause, watch the temperature gauge. The point of coldest temperature along the flightpath will be the tropopause penetration. Turbulence will be most pronounced in the temperature change zone on the stratospheric (upper) side of the sloping tropopause.

e) If possible, when crossing the jet, climb with a rising temperature and descend with a dropping temperature.

f) Weather satellite pictures are useful in identifying jetstreams associated with cirrus cloud bands. CAT is normally expected in the vicinity of jetstreams. Satellite imagery showing "wavelike" or "herringbone" cloud patterns are often associated with mountain wave turbulence. Pilots should avail themselves of briefings on satellite data whenever possible.

g) Last, but not least, monitor your radio – pilot reports can be invaluable and if you get caught by "the CAT," file a PIREP!

# SUMMARY

- Definition of CAT: 'Turbulence encountered outside of convective clouds'

- Definition of Jetstream: 'A river of high altitude wind a speed of 50 knots or greater following the planetary atmospheric wave pattern'.

- Three types of Jetstreams
  1. Polar Front
  2. Subtropical
  3. Polar Night

- The most common areas of Turbulence associated with Jetstreams greater than 110 knots are:

  1. Poleward side of Jestream.

2. At the core (Jetstream Maxima).
3. Between 2 Jetstreams in area of 'confluence' and downstream of that area.
4. In a sloping tropopause above the Jetstream.
5. In the Jetstream front below the core.
6. On the low pressure side of the core.

Horizontal shear and CAT turbulence intensity

| If the horizontal shear is: | Then the forecasted CAT turbulence is: |
|---|---|
| 25 to 49kt/90nm<br>50 to 89kt/90nm<br>>90kt/90nm | Moderate<br>severe<br>extreme |

Vertical shear and CAT turbulence intensity.

| If the vertical shear is: | Then the forecasted CAT turbulence is: |
|---|---|
| 3 to 5kt/1,000ft<br>6 to 9kt/1,000<br>10 to 14kt/1,000ft<br>> 15kt/1,000ft | light<br>moderate<br>severe<br>extreme |

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